

A QUANTUM PAST, PRESENT AND FUTURE PART I: A Light Bulb Moment* * Life is an ever-changing compilation of a dynamic ebb and flow that relies on adaptability and the refinement of every contributing feature. We might try to confine it within rigid bars of laws and formulae in an attempt to understand this profound vastness but every so often we are confronted with the reality of our own paltry. The early days of the 20th century was proof of this. Many physicists, intoxicated with the rapid preferment of the century gone by and emboldened by the fruits of their staggering feats, would proudly proclaim that everything to be learned and discovered in physics had been exhausted. However, this spirit would invoke an insurgence of unconventional ideas that defied classical physics. Ideas put forth would challenge the foundation upon which reality had been built, ideas such as Quantum theory. The story of Quantum theory begins in the early 1900s, amidst the bustling metropolis of Berlin where the physicist Max Planck was tasked with improving the efficiency of lightbulbs. He understood that he had to derive how much light a hot filament produces with the knowledge that light gave off electromagnetic waves. He tried to decipher how much light of each colour a hot object emits, however, his predictions opposed preexisting experiments. The scientist, described as a reluctant revolutionary, was forced to discard the existing theory and work with experimental measurements. According to the information he gained, light waves only carry energy in 'packets', known as quanta. High frequency light contains huge energy packets, while low frequency light contains small energy packets. This new rule of physics considered abstract for the time, but later on, Einstein found the correlation between Planck's idea and sharing of energy between light waves, these of which can exist in an infinite amount with a coordinating ability to absorb energy resulting in reduced heat in a space. But, as Planck hypothesized, smaller high frequency waves can only carry energy in huge packets as opposed to low frequency waves. Thus, most of the energy is carried by the less fussy low frequency waves. The common average energy that the quanta carries is what is meant by temperature. This basic understanding of the behavior of light and quanta set the stage for concepts birthed in the future such as superposition, entanglement, tunneling and coherence.

PART II: A Quantum Story of The Birds and the Bees- The evolution of life * From the Primordial Soup 4 billion years ago our home was born from chaos. It was an angry and scorched place with oceans of magma, pelted by meteorites. But as this molten soup began to cool and stabilize, the first anaerobic prokaryotes appeared. Over time these single celled organisms began to incorporate stragglers of genetic material to form more complex eukaryotic structures. 2 billion years after the birth of the earth, an interesting diversion would occur, and the first two kingdoms would come to be. It is hypothesized that, the archaeal cell would collect it's organelles through endosymbiosis to build the eukaryotic cell which is where the animal kingdom finds their origin. In another life form, cyanobacterium, chloroplasts were formed and this would later give rise to the complex plant kingdom.

One of the first organelles to be incorporated into a eukaryotic cell was the Mitochondria. The powerhouse. These structures produce energy to ensure the cells survival and reproduction. Glucose is broken down into ATP (Adenosine Triphosphate) which is the fuel for healthy cell function. This advent of endosymbiosis was crucial to the development of more complex life and is now a prominent feature in most living things. Mitochondria has made use of Quantum tunneling to ensure a continuous production of energy. Oxidation, Electron transport chain, Proton gradient and ATP synthase are all essential for ATP generation. The production of ATP in mitochondria relies on the movement of protons from the intermembrane space to the matrix, facilitated by an electrochemical gradient and the ATPase enzyme, which converts ADP to ATP using energy from proton flow. The electron transport chain (ETC) maintains this gradient, with complexes I, III, and IV actively pumping protons. Recent studies on complex I highlight specific subunits (ND2, ND4, ND5) that aid proton transfer via pathways shaped by amino acid protonation states and ion pairs, impacting energy barriers. Two mechanisms for proton transport are identified: Quantum Tunneling, which enables passage with lower energy than the barrier, and classical transport, which involves overcoming energy heights. In a study done by Abdallah Qaswal and associates on the Quantum Tunneling of Protons through Respiratory Complex I of Mitochondria, they were able to capture the potential functions of three subunits of respiratory complex 1 which has a potential barrier composed of amino acids. Using computer software, they were able to create energy profiles that captured the complexity of potential functions. These energy profiles created, and the values obtained were put through a series of calculations which proved that quantum tunneling was an energy saving efficient type of transport. Quantum conductance values were also looked at where a very broad range of quantum conductance values, including the physiological values

needed to generate the electrical potential of the Inner Mitochondrial Membrane (IMM), are provided by quantum tunneling. As a result, quantum tunneling may be an essential quantum biological mechanism for maintaining and enhancing the mitochondrion's ability to adapt to cellular stress. This is ensured by the reduced energy needed to tunnel protons, the ability to adjust to the sharp variations in the permeability of the mitochondrial membrane and preserve a physiological electrical potential for IMM, and the more regulated use of the number of complex I subunits and the total number of complex I proteins.

Another essential aspect in the development of a cell is DNA. A collection of all the traits that we have had throughout our entire existence can be found in the arrangement of 4 amino acids (Adenine-A, Cytoine-C, Guanine- G, and Thymine- T) which make up DNA. DNA as we know it has not always presented itself this way. It has undergone multiple changes and mutations, which are necessary for adaptation to ensure the continuation of a species. It can also sometimes be problematic causing harm to said species. An originating factor of DNA mutation can be attributed to Quantum Tunneling, specifically proton tunneling. Proton transfer along the hydrogen bonds of DNA that could lead to the displacement of hydrogen atoms, hence creating point mutations. Recently a study was done by Louie Slocombe, Marco Sacchi and Jim Al-Khalili who theoretically analyzed the hydrogen bonds between the Guanine-Cytosine (G-C) nucleotide. In their method, coupling to a surrounding heat bath (the cellular environment) caused the quantum system (the H-bond proton in the double-well potential) to experience dissipation and decoherence. Additionally, the environment served as a source of thermal activation, stimulating the proton to reach higher energy states that facilitate tunneling to the tautomeric (displaced) state on the right. They found that the probability of the proton being in the tautomeric form was much greater than what was predicted by previous studies of classical and semiclassical studies for this system. These results validate the extremely high possibility of proton tunneling being responsible for DNA mutations.

- Gaia's Green Thumb Plant life was among the first two kingdoms that developed from the archaic earth. However, they developed with unique features that contributed to changing the very nature of our planet. Plants were created with the ability to turn sunlight into energy (Photosynthesis), which is pivotal to the planet's survival. Quantum superposition and Quantum coherence are the two instruments of photosynthesis contributing to it's energy creation miracle. Chlorophyll produces an exciton, or packet of electrical energy, when it absorbs light. The exciton doesn't follow a single path but exists in a superposition of multiple states, effectively exploring all possible routes to the reaction centre simultaneously. Quantum coherence, in which the exciton's wave-like characteristics enable it to sustain its quantum state for an extended amount of time, hence improving the energy transfer process, is essential to this simultaneous investigation. Photosynthesis is extremely efficient because of the nearly seamless energy transfer and charge separation made possible by quantum mechanical processes. Scientists have hypothesised that singular photons are responsible to kickstart photosynthesis since the amount of sunlight that filters down to plant cells is very sparse. Researchers were able to replicate this phenomenon, of watching a singular packet of light start the process. This quantum light experiment used the light harvesting 2 complex (LH2) of purple bacterium to demonstrate how gathered light (existing as waves) was converted into energy after photosynthesis because of a photon passing through the photosynthetic system, first existing as light waves and then as energy.
- Maintaining Balance-Thermodynamics and Entropy The study of the connection between heat, work, temperature, energy, and entropy as well as how these ideas relate to the characteristics of matter and radiation are known as thermodynamics. There are four laws of thermodynamics, The zeroth law, first law, second law and third law, which govern energy and heat. Temperature measurement is made possible by the Zeroth Law, which defines thermal equilibrium. According to the First Law, energy can only be transformed; it cannot be created or destroyed. The Second Law states that heat does not naturally move from cold to hot in an isolated system because entropy, or disorder, always rises. A system's entropy approaches a constant minimum value as its temperature approaches absolute zero, according to the Third Law, suggesting that absolute zero is unachievable. The laws of thermodynamics manifest itself in biological systems through energy transformation where energy is continuously transformed by living things such as in Photosynthesis. Biological organisms are open systems, as opposed to the closed systems to which the Second Law typically applies. They interact with their environment by exchanging matter and energy. Living cells preserve their internal order

and low-entropy state even as the universe’s overall entropy rises by absorbing energy (such as food) and releasing energy in the form of waste and heat. Thermodynamic principles also aid in forecasting the course and viability of biological processes. Quantum thermodynamics finds itself applicable to biological systems to explain the efficiency of various processes that sustain life. An example of efficient energy transfer is photosynthesis where energy is transformed and forms part of an open system interacting with other environmental factors. It is also known that enzymatic reactions employ the first and second law of thermodynamics. These laws can be displayed at a quantum level through quantum coherence and quantum tunnelling for efficient energy transfer to increase reaction rate.

- Finding the Cure Humans have been faced with multiple plagues and diseases during our history. Typically, nature will use disease as a form of natural selection causing it to be a catalyst for evolution. However, as our knowledge of sicknesses improved, so did our methods to cure them. From ancient herbal remedies to modern pharmacology, we have developed different mechanisms to formulate medication. Drug design is one of those methods which refers to creating new drugs based on biological target knowledge. Most often, the drug is a small, organic molecule that either activates or inhibits the function of a biomolecule, giving the patient a therapeutic benefit. Computational chemistry is an aid to Drug design as it speeds up the process of finding new drugs by virtually designing and optimizing drug molecules using physics-based algorithms and computer simulations. Potential drug targets can be found, large compound libraries can be virtually screened, a molecule’s characteristics, such as binding affinity and efficacy, can be predicted, and candidate structures can be refined prior to laboratory testing. Quantum mechanical methods, which provide unprecedented insights into the behaviour and properties of molecules at the atomic scale, form the basis of computational chemistry. These methods make fundamental electronic structures, energy, and properties clear by solving the Schrodinger equation (a pivotal equation in quantum mechanics), which is crucial for understanding a range of chemical systems. Density Functional Theory (DFT), which is a computational quantum mechanical method, is unique in that it can be used to examine the electronic properties of atoms, molecules, and solids in a variety of ways. Quantum chemistry can now make even more predictions thanks to advanced techniques like post-Hartree-Fock methods and time-dependent DFT. These techniques offer more information about how molecules move and how electrons are excited. Molecular dynamics simulations supplement quantum mechanical methods by showing how molecules move and interact over time. They achieve this by drawing parallels between what actually occurs and what scientists believe should theoretically occur.
- Let’s get metaphysical! From the beginning of this essay, we have been able to track the similarities between us humans and other living things as we have the same building blocks and similar biological systems. But a defining factor that sets us apart from other life forms is our cognition and consciousness, the intangible aspects of our survival which has launched our species to be at the apex. It has been hypothesized that these intangible aspects of our selves may be affected by quantum mechanics. Both quantum cognition, which models human behaviour and decision-making using the mathematical structure of quantum mechanics, and the quantum brain hypothesis, which proposes quantum processes like superposition and entanglement directly produce awareness within neurons. A few areas of quantum theory have been identified to explain the quantum effects on the brain and consciousness. According to Orch-OR theory, microtubules are capable of sustaining quantum coherence that is, acting as a single quantum system long enough to affect brain activity and contribute to conscious experience. The unity of conscious experience may be explained by instantaneous communication across the brain made possible by entanglement between particles in various neurons. According to certain theories, quantum tunnelling may have an impact on neurotransmitter release at synapses, affecting brain transmission in ways that are not entirely explained by conventional models. If the quantum brain hypothesis proves to be true, it could revolutionize the way we think about creativity, free will and our perception of reality.

PART III: How Quantum is Life? It is most intriguing to ponder over how a theory, accepted with apprehension, then widely debated over has transformed our understanding of the world and the intricate mechanisms we rely on. Quantum mechanics has found an irreplaceable spot in the scientific world as well as the field of Biology. It would stand to reason that a field of study exploring the interactions between the smallest

bits of matter would form an essential part of the understanding of ourselves, our origins and the factors that contribute to our continuation. Entanglement, Superposition, Tunnelling and Coherence are some of the answers to integral questions that has reshaped our worldview.

As we look more closely into quantum theory and the way it effects heat, light and energy, the cornerstones of physics, we realise that quantum mechanics has been gazing back at us from our primitive campfires since the dawn of time, it has always been around and within us.